Nuclear Weapons Stockpile Stewardship

Lawrence Livermore National Laboratory was established in 1952 to help ensure national security through the design, development, and stewardship of nuclear weapons. National security continues to be the Laboratory's defining responsibility. Livermore is one of the three national security laboratories that support the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE).

Livermore plays a prominent role in NNSA's Stockpile Stewardship Program for maintaining the safety and reliability of the nation's nuclear weapons. The Stockpile Stewardship Program integrates the activities of the U.S. nuclear weapons complex, which includes Livermore, Los Alamos, and Sandia national laboratories as well as four production sites and the Nevada Test Site. It is an extraordinarily demanding program. As the nuclear weapons in the stockpile continue to age, Laboratory scientists and engineers are challenged to ensure their performance and refurbish them as necessary without conducting nuclear tests.

Working with the other NNSA laboratories, Livermore is attending to the immediate needs of the stockpile through assessments and actions based on a combination of laboratory experiments and computer simulations of nuclear weapon performance. In addition, the Laboratory is acquiring more powerful experimental and computational tools to address the challenging issues that will arise as the nation's nuclear weapons stockpile continues to age. These vastly improved scientific capabilities will be used by experienced nuclear weapons designers to train and evaluate the skills of the next generation of stockpile stewards, who will rely on the new tools.

Engineering test stand in support of the W87 Life-Extension Program.

Certifying Stockpile Safety and Reliability

Livermore is a key participant in formal review processes and assessments of weapon safety, security, and reliability. In 2002, the seventh cycle of annual certification of the stockpile for the President was completed. Now called the Annual Assessment Review, the formal process is based on the technical evaluations made by the laboratories and on advice from the three laboratory directors, the commander of the U.S. Strategic Command, and the Nuclear Weapons Council. To prepare for this process, Laboratory scientists and engineers collect, review, and integrate all available information about each stockpile weapons system, including physics, engineering, chemistry, and materials science data. This work is subjected to rigorous, in-depth intralaboratory review and to expert external review, including the formal use of red teams.

For the Annual Assessment Review—and the formal certification of refurbished warheads—weapons experts depend on an extensive range of aboveground testing, vastly improved simulation capabilities, and the historical nuclear test database. Livermore and Los Alamos are also developing and beginning to apply a rigorous set of quantitative standards as the basis for formal certification actions and setting programmatic priorities. The methodology—quantification of margins and uncertainties (QMU)—is analogous to the use of engineering safety factors in designing and building a bridge.

E. O. Lawrence Award for Bruce Goodwin

Bruce Goodwin, a Laboratory physicist and currently associate director for Defense and Nuclear Technologies, was awarded an E. O. Lawrence Award in 2002. “I came up with some theories for the equations of state for plutonium under extreme conditions derived from peculiarities I saw in nuclear test data,” Goodwin said of his work. “I was flying in the face of 40 years of research, and the critics said it couldn’t be true.” However, Goodwin’s theories proved true, and the work helped pave the way for the Stockpile Stewardship Program and its emphasis on developing a much better understanding of the fundamental science underlying nuclear weapons performance through theory, modeling, and experiments.

Weapon Surveillance to Include Pit Inspections at Livermore

The Laboratory conducts a wide range of stockpile surveillance activities to assess the condition of Livermore-designed weapons in the stockpile and to better understand the effects of aging on weapons. These surveillance activities now include evaluating the pits in the primaries of Livermore-designed weapons. Livermore is the design laboratory for four weapon systems in the stockpile: the W87 and W62 ICBM warheads, the B83 bomb, and the W84 cruise missile.

Previously, these pit surveillance activities were carried out at Los Alamos. Transfer of the responsibility better balances the workload between the two laboratories and takes advantage of improved surveillance technologies developed at Livermore. In particular, surveillance will include the use of computed tomography to reconstruct three-dimensional radiographic images of pits. The technique is similar to medical tomography but uses much higher energy x rays so that small features can be resolved. In the future, this new tool may reduce the number of pits that have to be destroyed as part of the surveillance program.

To prepare for pit surveillance, the Laboratory installed new equipment for pit inspections in the Plutonium Facility and developed surveillance procedures. NNSA also conducted an in-depth review to qualify the program. In FY 2002, the Laboratory logged its first “scorable” pit surveillance evaluation, and the program is now fully operational.

Life Extension of the W87 ICBM and W80 Cruise Missile Warheads

Livermore's W87 Life-Extension Program, begun in late 1994, continues to meet all of its major milestones. Refurbishment of the W87 ICBM warhead, the design with the most modern safety features in the stockpile, extends the lifetime of the weapon to beyond 2025. With the final unit scheduled for completion in 2004, refurbished W87 warheads are being delivered to the Air Force after assembly at the Pantex Plant. The Laboratory developed the refurbishment design and is now collaborating with the production plants to ensure the quality of the W87 refurbishment work while maintaining the targeted production rate.

Lawrence Livermore and Sandia–California national laboratories have also assumed responsibility for the W80 Life Extension Program. The W80, designed by Los Alamos, is currently deployed in air-launched and sea-launched cruise missiles. Substantial test activities were initiated in 2002 in support of a schedule that calls for the first production unit of the refurbished warheads in FY 2007.

Experiments to Understand Nuclear Weapon Performance

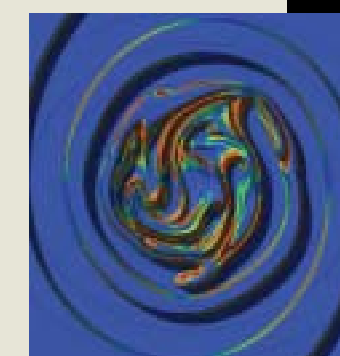
In 2002, researchers successfully carried out the first hydrodynamic experiments in the Contained Firing Facility (at left) at Site 300, the Laboratory's experimental test area 24 kilometers southeast of the main site. In these critically important experiments for stockpile stewardship, scientists study the performance of mock weapon primary pits as the pits are imploded by high explosives. With construction completed in 2001, the Contained Firing Facility houses the Laboratory's most modern facility for conducting these types of tests. In a firing chamber designed to withstand repetitive tests using up to 60 kilograms of high explosives, the facility minimizes the noise, blast pressures, and generation of hazardous materials resulting from experiments.

Many other types of experiments are also being conducted to understand the performance of weapon components and materials. For example, in 2002, researchers fired the ninth and final subcritical experiment in the Oboe series. These highly instrumented tests, conducted in an underground alcove at the Nevada Test Site, provide data on the behavior of plutonium when it is strongly shocked and how that behavior differs depending on the age of the material or manufacturing processes used. Because plutonium has such complex material properties and is so important for weapon performance, Livermore has acquired and is using unique laboratory equipment, such as the most powerful transmission electron microscope in the NNSA complex, for metallurgical and chemical examination of plutonium.

3D Weapons Physics Simulations

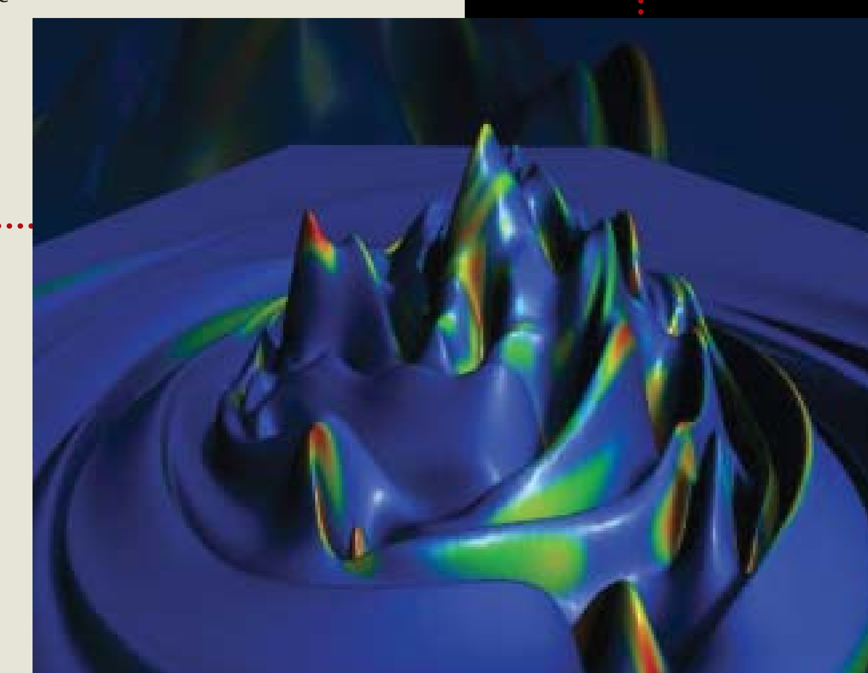
Increasingly sophisticated physics simulations are made possible by the arrival at the Laboratory of successively more powerful computers as part of the NNSA's Advanced Simulation and Computing (ASCI) program. The computer models being run on Livermore's ASCI White supercomputer, capable of more than 12 trillion operations per second (teraops), range from simulations of quantum molecular activity and multiscale models of material properties to three-dimensional (3D) simulations of full weapon performance.

Teams of scientists from Livermore and Los Alamos each have used ASCI White to complete 3D simulations of a complete warhead explosion. Three-dimensional simulation is critically important because nuclear explosion phenomena—such as high-explosive detonation, hydrodynamics, and radiation transport—are not always symmetric because of aging and manufacturing variations. The size and scale of ASCI White allowed the two laboratories to perform calculations with a level of spatial resolution and a degree of realism in the physics models that had not previously been possible.



Livermore's calculation, for example, ran a total of 43 days on 1,024 processors of the ASCI White computer and produced tens of trillions of bytes of data. Sandia has also used ASCI White to perform extremely large, sophisticated structural dynamics calculations. Both Sandia and Los Alamos performed their calculations remotely from New Mexico. The speed, large memory, and stability of ASCI White were essential elements contributing to the successful series of calculations.

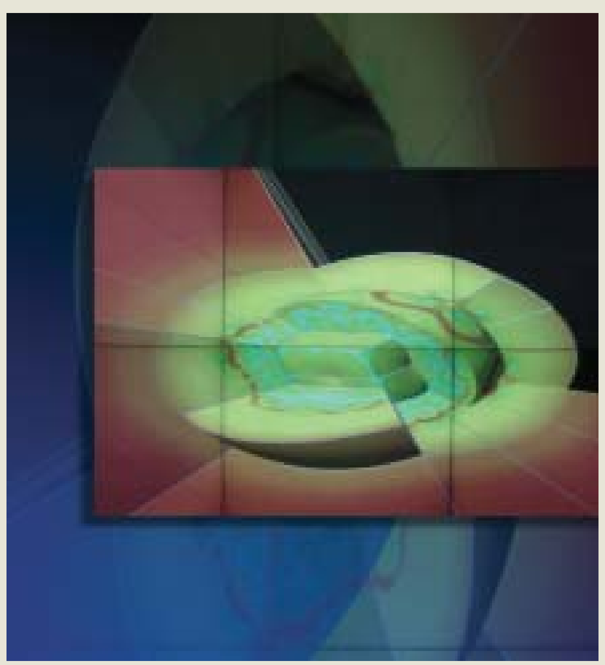
One challenge for researchers is analyzing the huge datasets that are generated in simulations. As part of ASCI's Visual Interactive Environment for Weapons Simulation (VIEWS) effort, advanced tools are being developed for visually exploring data, such as that generated in a calculation of the turbulent mixing of fluids of different density (shown).



A Detailed Model of High-Explosive Detonation

Laboratory researchers have developed an advanced computer simulation model to better understand the details of the detonation process for high explosives. The phenomena are complex because of the extreme conditions that occur during detonation—temperatures to 3,500 kelvins, pressures to 500,000 times Earth's atmosphere, and billionth-of-a-second timescales. In addition, explosives are highly heterogeneous materials consisting of small crystallites of an explosive molecule bonded together with a plastic binder. More than 100 billion of these crystallites, called grains, are irregularly packed into a cubic inch of explosive.

Livermore's grain-scale simulations have modeled the interaction of the detonation shock wave in a small cube of HMX high explosive. The cube contained 100,000 grains and realistically included voids, binder material, and intragranular defects, which greatly affect the detonation process. In addition to developing the model, Livermore researchers conducted sophisticated experiments to gather data characterizing the molecular behavior at high temperature and pressure of the explosive materials and detonation products. The results of these grain-scale simulations, run on the ASCI White supercomputer, will provide the basis for more realistic models for the detonation process in larger-scale simulations of the performance of real weapon systems.



The World's Most Powerful Computer

In November 2002, DOE Secretary Spencer Abraham announced that International Business Machines (IBM) Corporation had won a $290-million, multiyear contract to build the two fastest supercomputers in the world—ASCI Purple and Blue Gene/L—both to be sited at Livermore. ASCI Purple, a 100-teraops (trillion operations per second) machine, will

enable 3D simulations with high-fidelity physics models of the performance of a full nuclear weapon system. The supercomputer will be powered by 12,544 microprocessors in 196 individual computers interconnected via an extremely high-bandwidth, superfast data highway. The system will also have 50 terabytes (trillion bytes) of memory, which is 400,000 times more capacity than the average desktop computer and two petabytes (quadrillion bytes) of disk storage, the content of approximately one billion books.

In addition, the Laboratory and NNSA are working with IBM on a scalable "ultracomputer" called BlueGene/L. When completed, BlueGene/L will have a peak performance of 360 teraops using 130,000 processors. It will be capable of performing an important subset of computational problems—those that can be easily divided to run on many thousands of processors.

This expansion of Livermore's computing power has required construction of the Terascale Simulation Facility (TSF), a $92-million construction project launched with a groundbreaking ceremony in April 2002. The TSF will encompass approximately 253,000 square feet, including 48,000 square feet of raised computer floor for the high levels of power and cooling. Work on the facility is proceeding rapidly. One of two machine rooms will be completed in 2004 in time for the arrival of ASCI Purple.

The TSF will also include an Advanced Simulation Laboratory for the development of the data assessment hardware and software to analyze the extremely large data sets produced by ASCI calculations. Offices there will house approximately 288 staff members in secure and open work areas.

"Early Light" at the National Ignition Facility

In December 2002, the National Ignition Facility (NIF) project reached a major milestone when the first four of 192 laser beams were activated and generated more than 43 kilojoules of infrared light (photos this page). The following month, the first shot was fired in which laser light—frequency converted from infrared to ultraviolet—reached the target chamber. Achievement of "early light" at NIF marks the beginning of an important transition for NIF from a construction project to an experimental facility.

NIF is a cornerstone of the Stockpile Stewardship Program. The 192-beam laser facility, when completed, will be the world's most energetic laser, generating 1.8 megajoules of ultraviolet light. Many of the fundamental physics processes of thermonuclear detonation will, for the first time, become accessible for laboratory study and analyses. By firing its laser beams in unison and focusing its energy on a marble-size target for a few billionths of a second, NIF will generate the temperatures and pressures needed to conduct experiments to validate weapons-physics computer codes and address important issues of stockpile stewardship. Experiments on NIF will evaluate the feasibility of inertial fusion energy, a long-standing program goal within DOE for energy security. In addition, NIF will also allow laboratory studies of astrophysics and materials under conditions similar to those found in stars.

The early light shots successfully demonstrated all of the systems in NIF needed to produce and direct energetic laser beams to the target chamber center, including laser components and optics, the laser beampath and supporting utilities, the power conditioning system, diagnostics, alignment, and computer controls. With just the first four of 192 laser beams functioning, NIF is fast approaching the energy capability of the Laboratory's now-decommissioned Nova laser, which previously was the largest laser system in the world. An experimental program will soon begin using the first four laser beams, and NIF's capabilities will grow as more beams are brought online.

Early light was made possible in 2002 by the major progress achieved by the NIF project team. Overall, the NIF project was more than two-thirds complete by year's end. The beampath infrastructure in Laser Bay 2 (96 beams, including the four lasers brought into operation) was completed in May, and the utilities required for the first laser beams were installed. In addition, the 10-meter-diameter target chamber was aligned in the target bay. Both the beam enclosures to transport the first laser beams and the supporting diagnostics systems were also installed. In the Optics Assembly Building, which contains Class 10,000 through Class 100 clean-room facilities, more than 120 line replaceable units for the first four beams—optical components including mirrors, lenses, polarizers, windows, and crystals—were assembled and tested before being mounted in NIF.

The NIF project reached another significant milestone with the accomplishment of two years (2.6 million hours) of work on the site without a lost workday accident. In December 2002, the NIF team received its second National Safety Council Perfect Year Award. In December 2001, the NIF team was awarded its first Perfect Year Award in recognition of the project's first million hours without a lost-time accident.